Radar Physics - Part 1

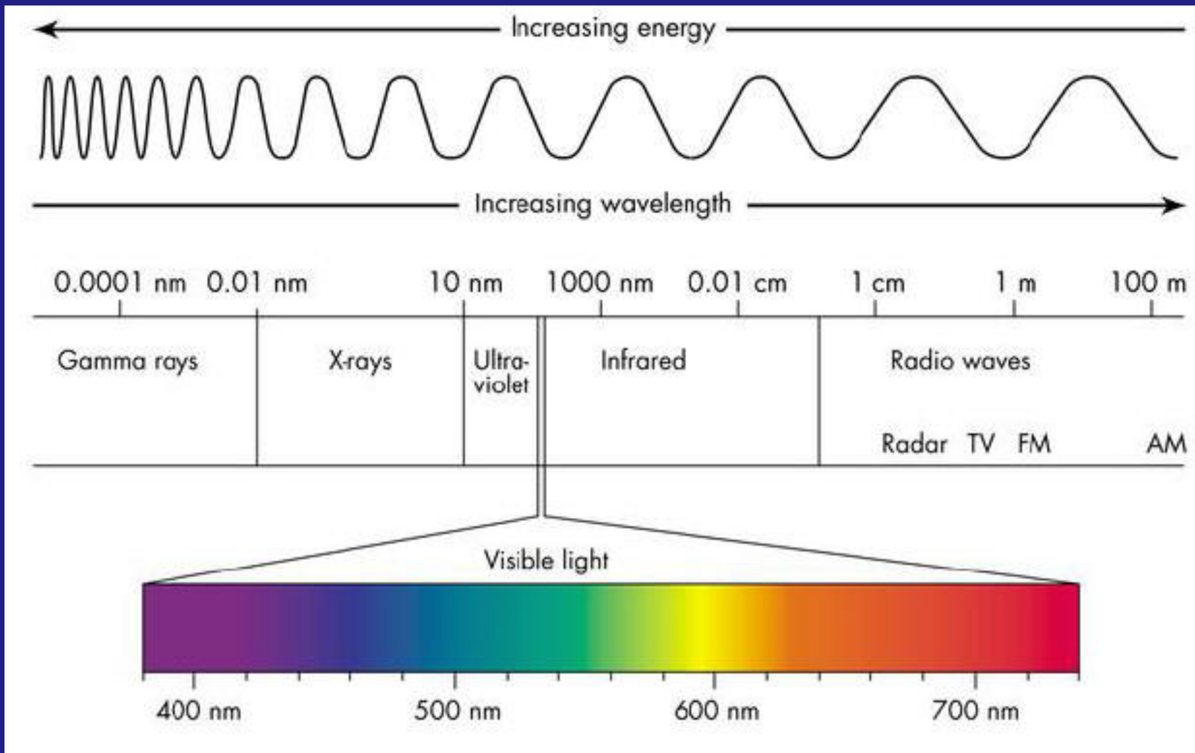
Anthea J. Coster

__Outline__

Electromagnetic spectrum

Radio waves and propagation

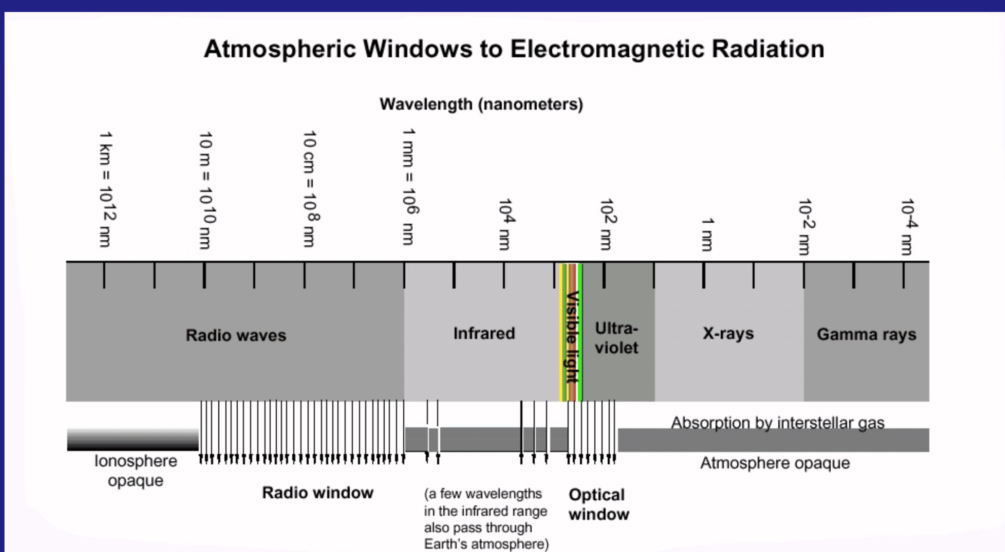
The Electromagnetic Spectrum

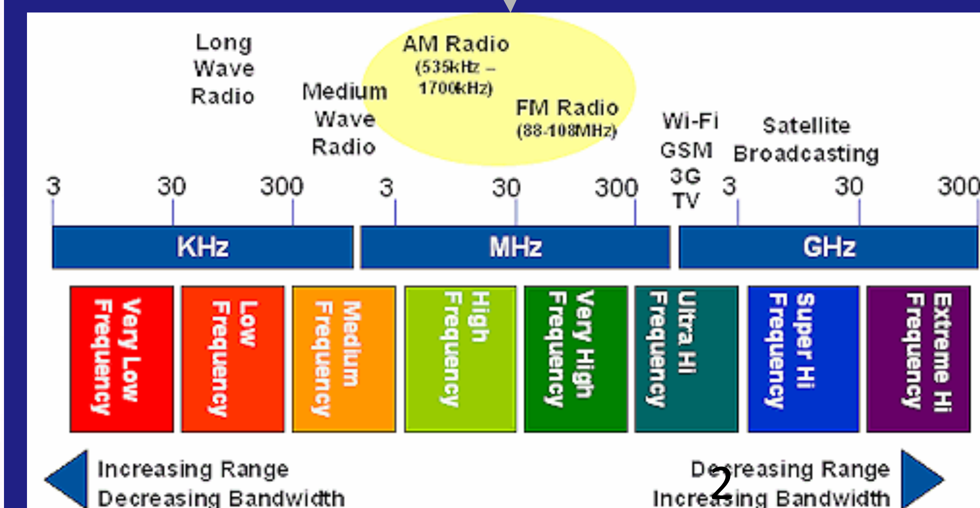


RADAR

Remote sensing using radio waves:

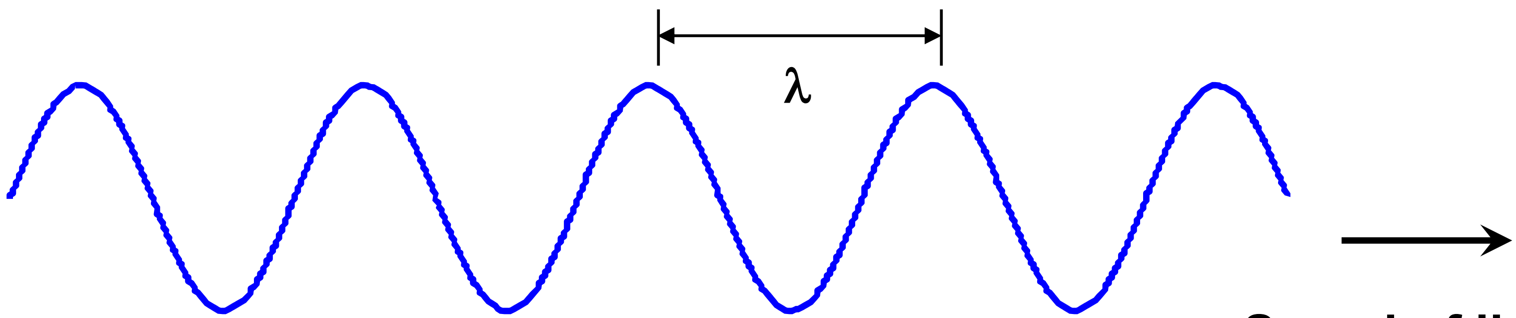
Just light we can't see without tools.





Properties of Waves

Relationship Between Frequency and Wavelength



Speed of light, c

$c = 3\text{x}10^8$ m/sec
= 300,000,000 m/sec

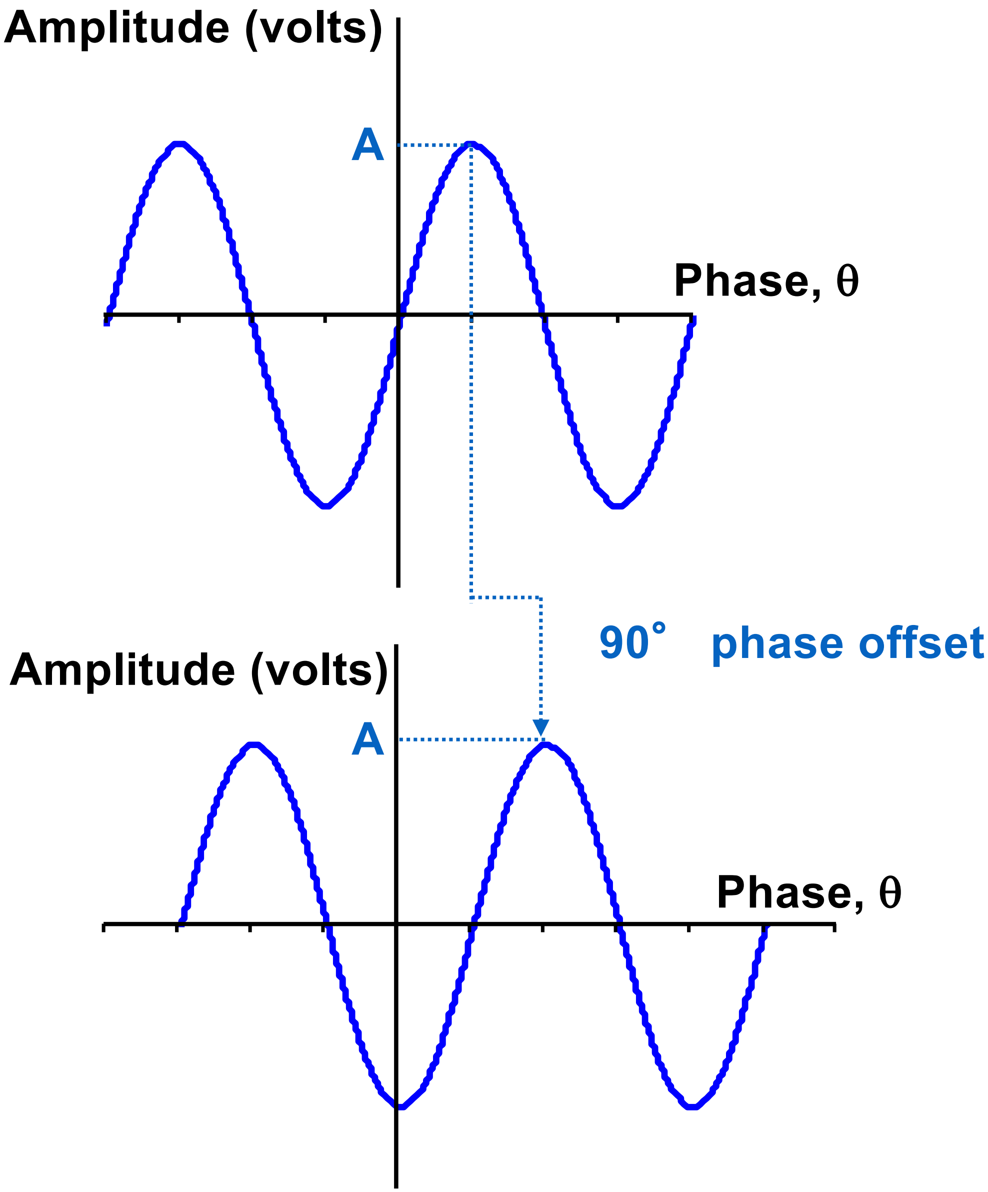
$$\text{Frequency (1/s)} = \frac{\text{Speed of light (m/s)}}{\text{Wavelength } \lambda \text{ (m)}}$$

Examples:

Frequency	Wavelength
100 MHz	3 m
1 GHz	30 cm
3 GHz	10 cm
10 GHz	3 cm

Properties of Waves

Phase and Amplitude



$$A\sin(\theta)$$

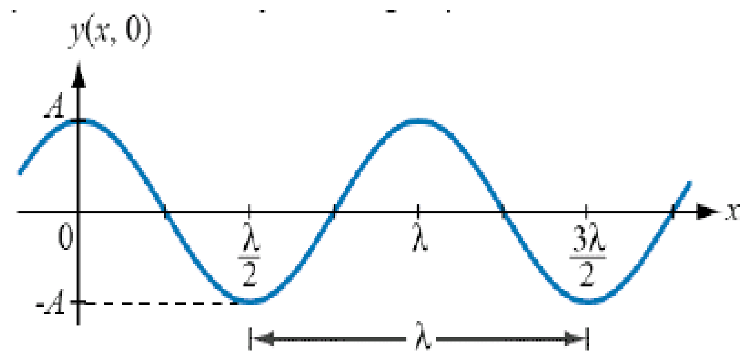
$$A\sin(\theta - 90^o)$$

Radio Waves

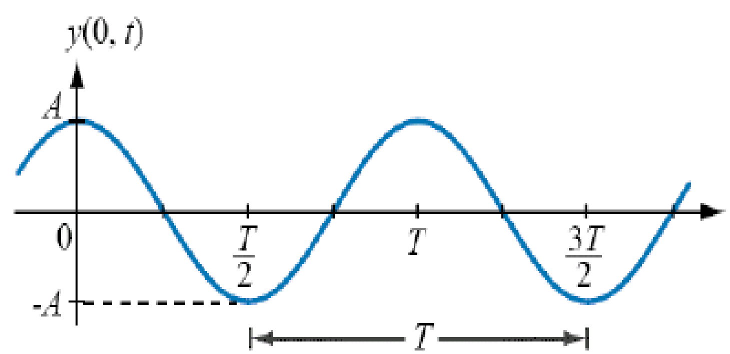
$$y(x, t) = A\cos(\omega t - kx + \phi_o)$$

Angular frequency
$\omega = 2\pi f = 2\pi/T$

Wavenumber
$k = 2\pi/\lambda$



(a) y(x, t) versus x at t = 0

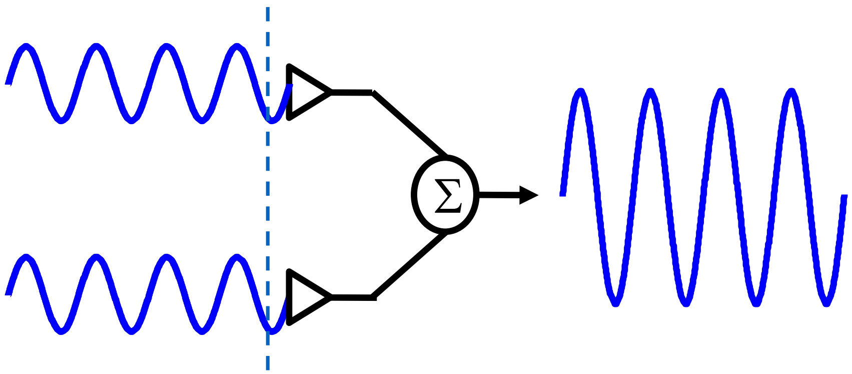


(b) y(x, t) versus t at x = 0

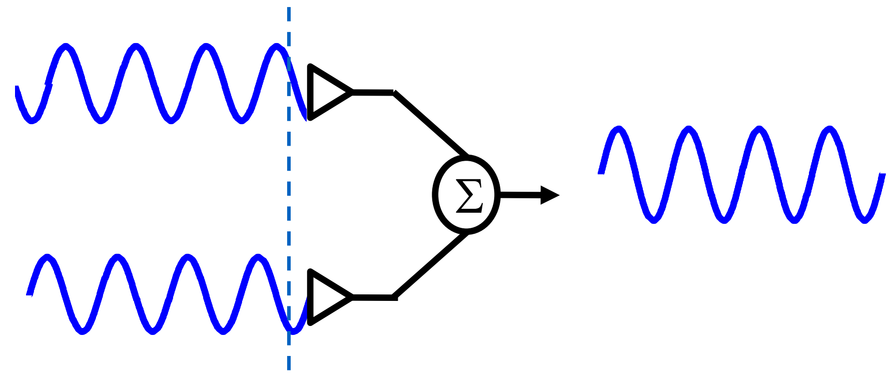
Wave phase velocity
$c = f\lambda = \omega/k = 3\text{x}10^8\ m/s$

Frequency (1/s) = $\dfrac{\textbf{Speed of light (m/s)}}{\textbf{Wavelength l (m)}}$

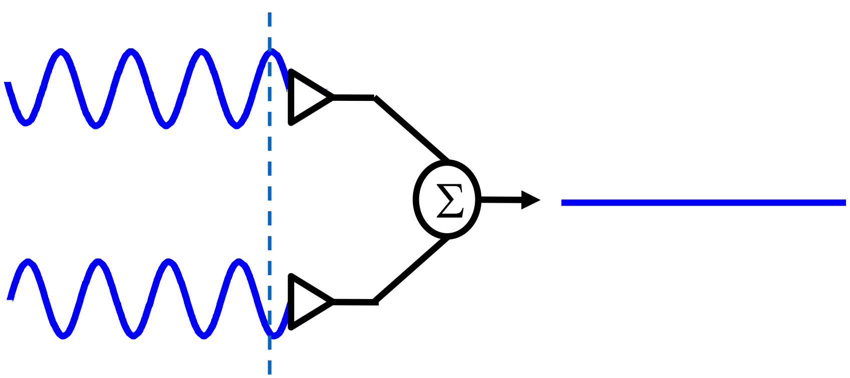
Properties of Waves
Constructive vs. Destructive Addition



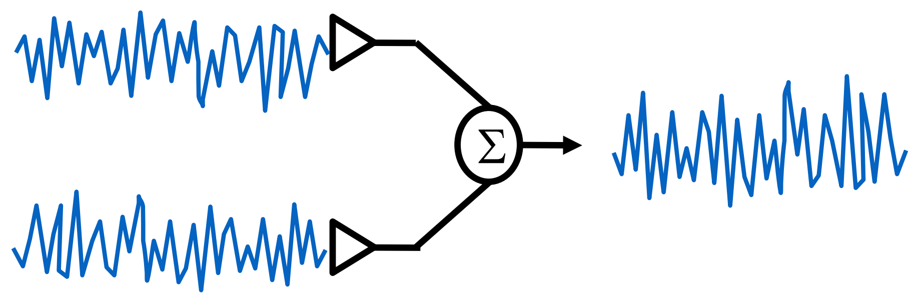
Constructive
(in phase)



Partially Constructive
(somewhat out of phase)



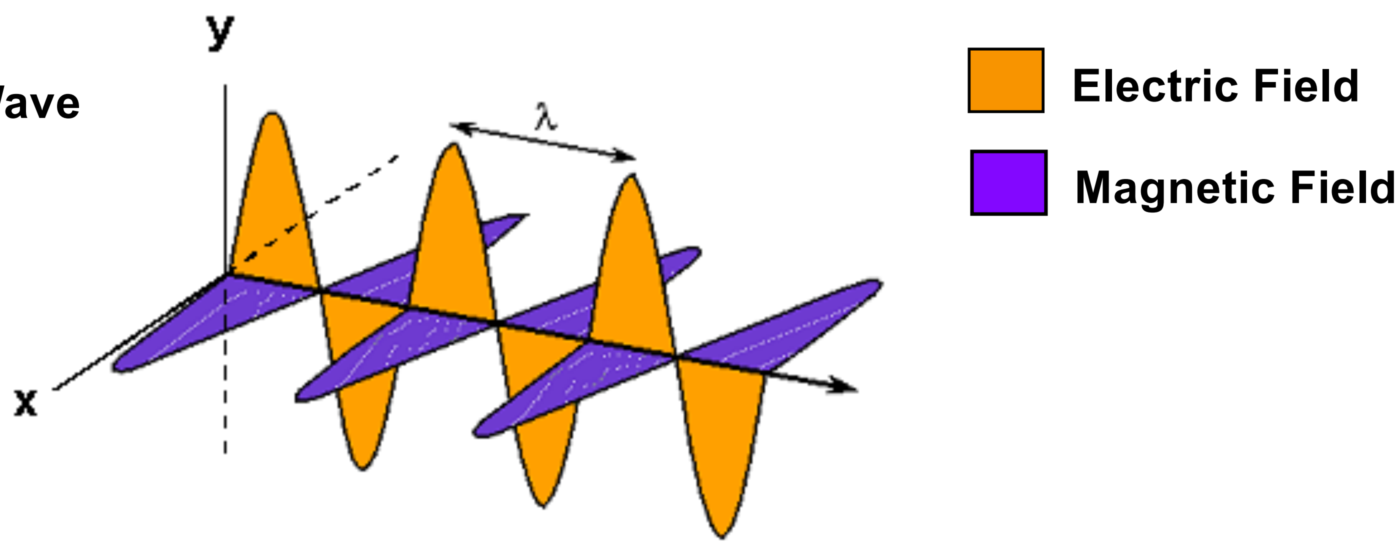
Destructive
(180° out of phase)



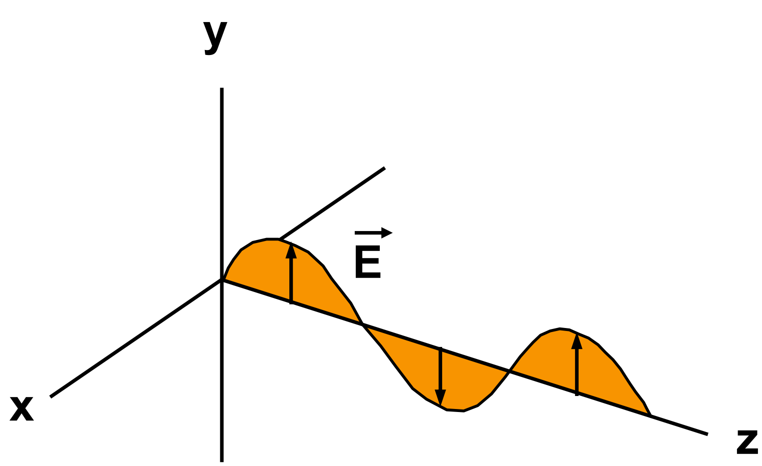
Non-coherent signals
(noise)

Polarization

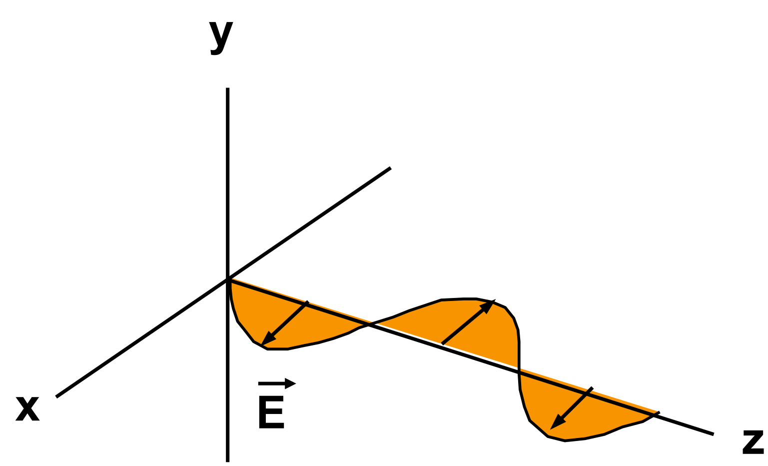
Electromagnetic Wave



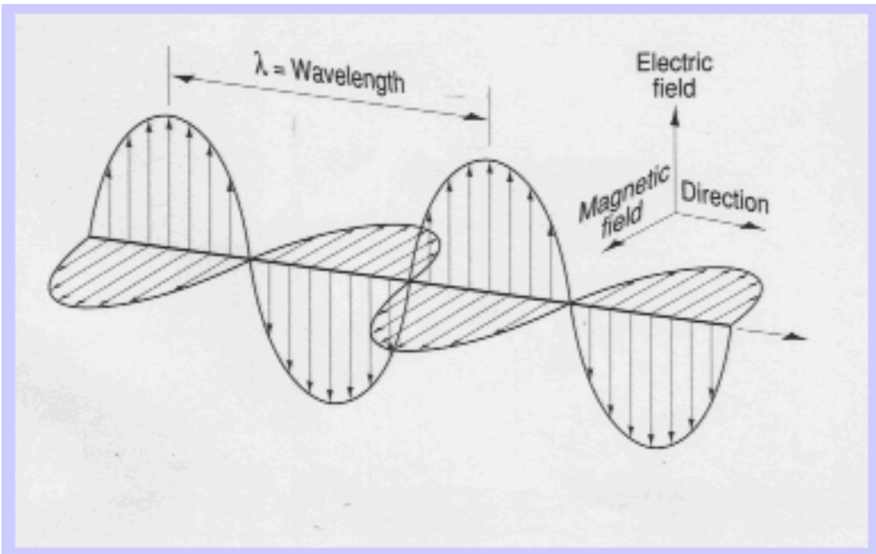
Vertical Polarization



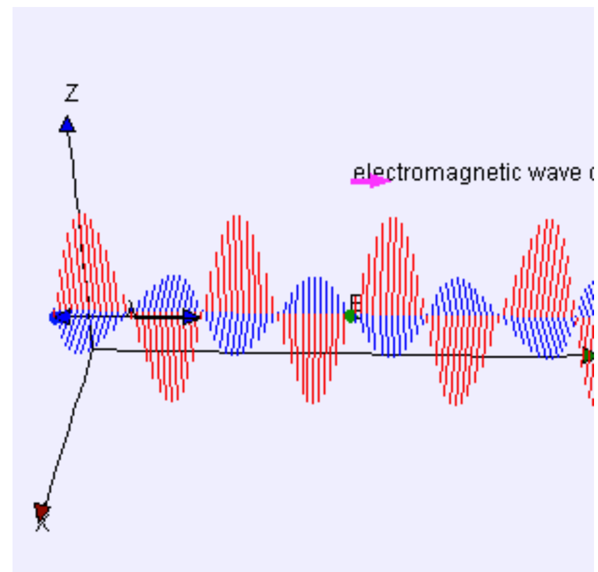
Horizontal Polarization

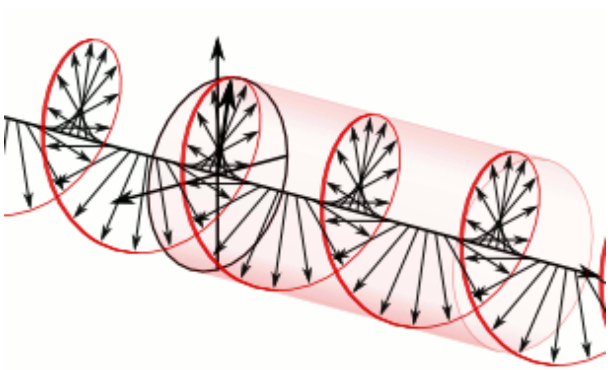


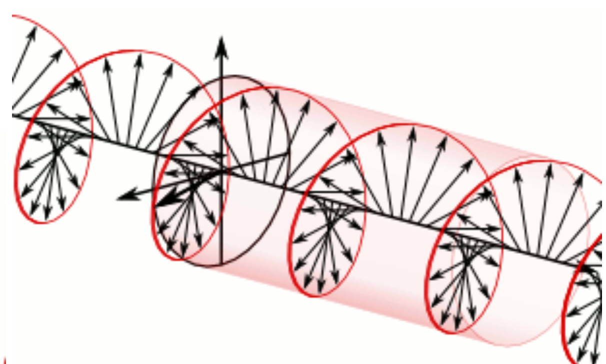
TEM Waves: ***Transverse electromagnetic* (*TEM*) *modes*** **neither electric nor magnetic field in the direction of propagation**



Electromagnetic waves in free space propagate in TEM mode





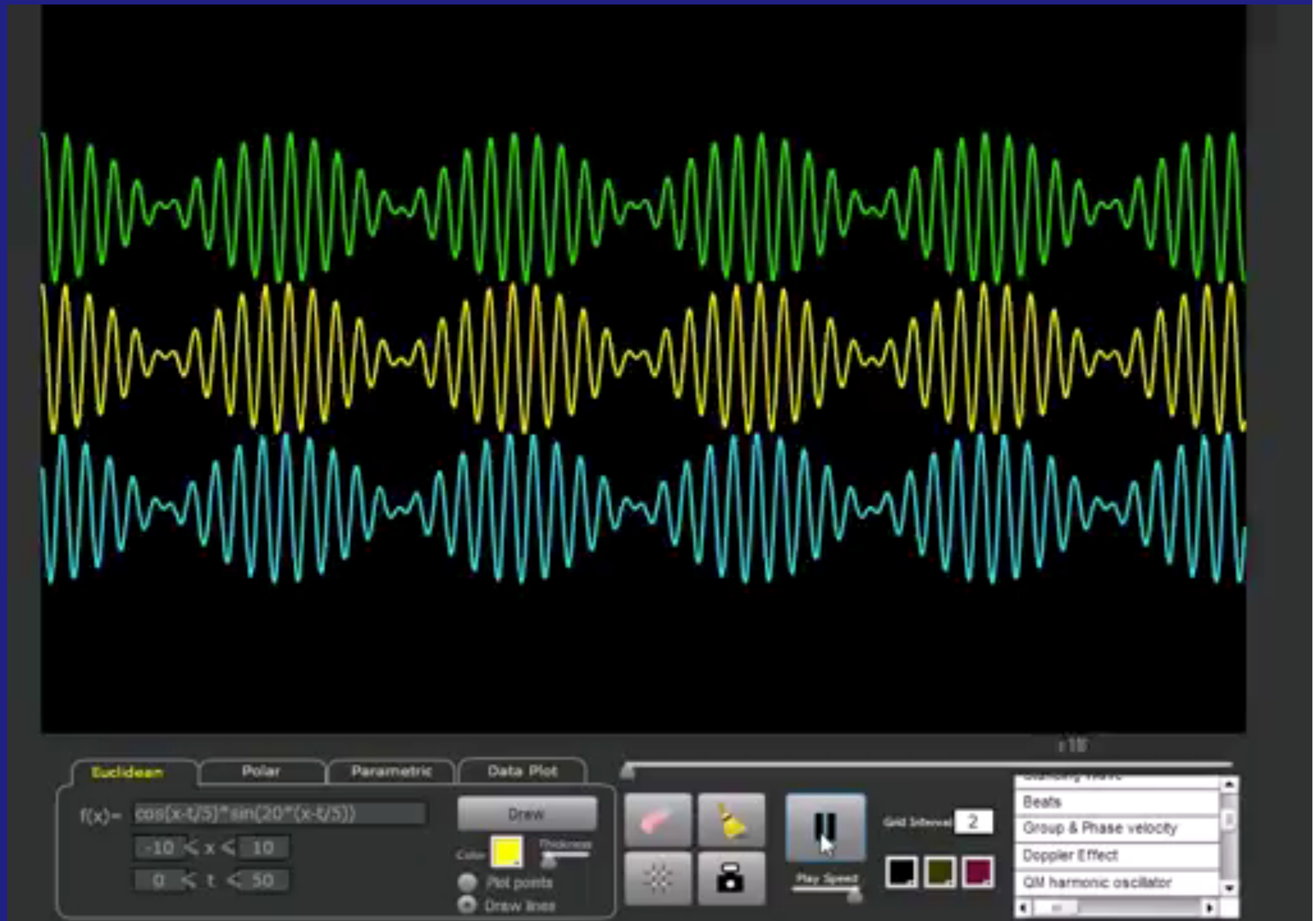


Phase Velocity, Group Velocity, Index of Refraction

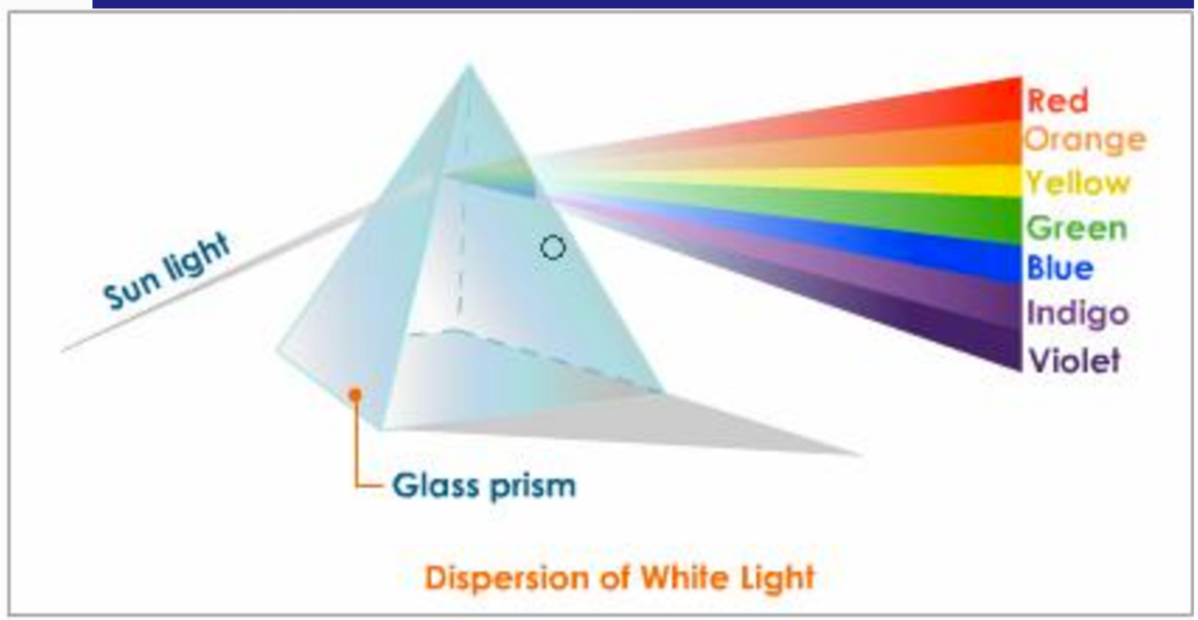
$$v_\mathrm{p} = \frac{\omega}{k}$$

$$v_g \equiv \frac{\partial \omega}{\partial k}$$

$$n = \frac{c}{v_\mathrm{p}}.$$



Refraction and Dispersion

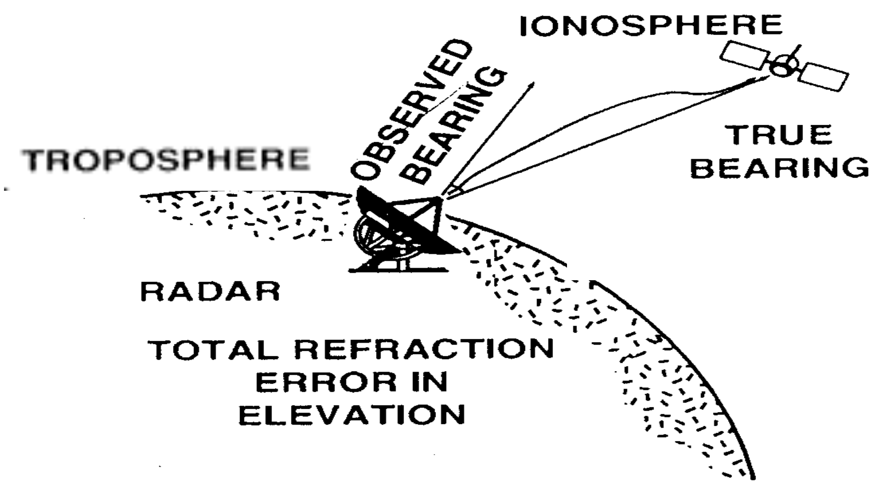


ISR School 2017

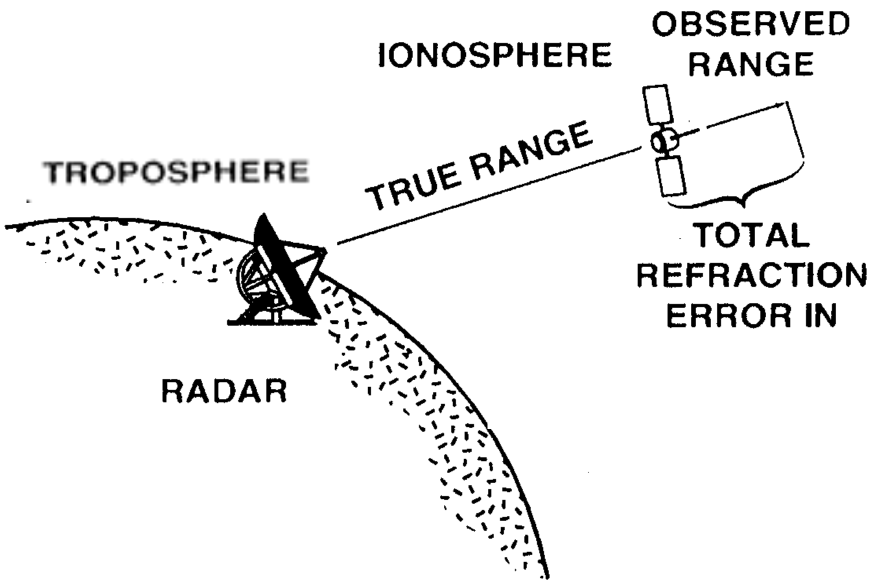
From Attila Komjathy, JPL

Illustration of Atmospheric Effects

Elevation Refraction



Range Delay



Index of Refraction $n = \frac{c}{v_p}.$ in the Ionosphere

$$n^2 = 1 - \frac{X}{1 - iZ - \frac{\frac{1}{2}Y^2 \sin^2\theta}{1-X-iZ} \pm \frac{1}{1-X-iZ}\left(\frac{1}{4}Y^4 \sin^4\theta + Y^2\cos^2\theta(1-X-iZ)^2\right)^{1/2}}$$

n is the index of refraction

$$X = \frac{\omega_N^2}{\omega^2} \quad Y = \frac{\omega_H}{\omega} \quad Z = \frac{\nu}{\;} \quad \omega_N = \left(\frac{Ne^2}{\varepsilon_0 m_e}\right)^{1/2} \quad \omega_H = \frac{e|B|}{m_e}$$

ω = the angular fre ... the radar wave,

$Y_L = Y\cos\theta$, $Y_T = Y\sin\theta$,

θ = angle between the wave vector $\overline{k}$ and $\overline{B}$,

$\overline{k}$ = wave vector of propagating radiation,

$\overline{B}$ = geomagnetic field, N = electron density

e = electronic charge, m_e = electron mass, ν = electron collision frequency

and ε_0 = permittivity constant.

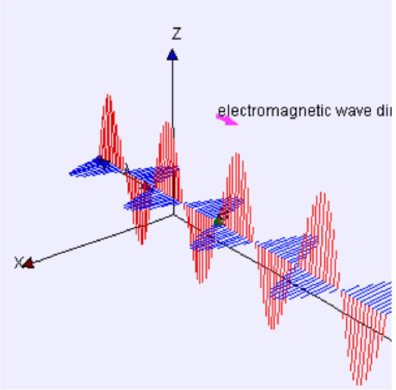
Dispersion relation: the concept

Key concept for wave behavior within a propagation medium.

Describes the relationship between SPATIAL frequency (wavelength) and TEMPORAL frequency.

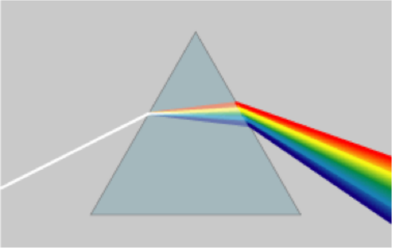
Some wave modes relate wavelength to frequency **linearly,** but waves in most media have **nonlinear** relation between wavelength and frequency.

Linear dispersion example:
EM radiation propagation through free space
(wavelength / velocity = c)



http://weelookang.blogspot.com/2011/10/ejs-open-source-propagation-of.html

Nonlinear dispersion example:
splitting of light through a prism
(effective speed of light depends on wavelength due to glass' non-unity index of refraction)



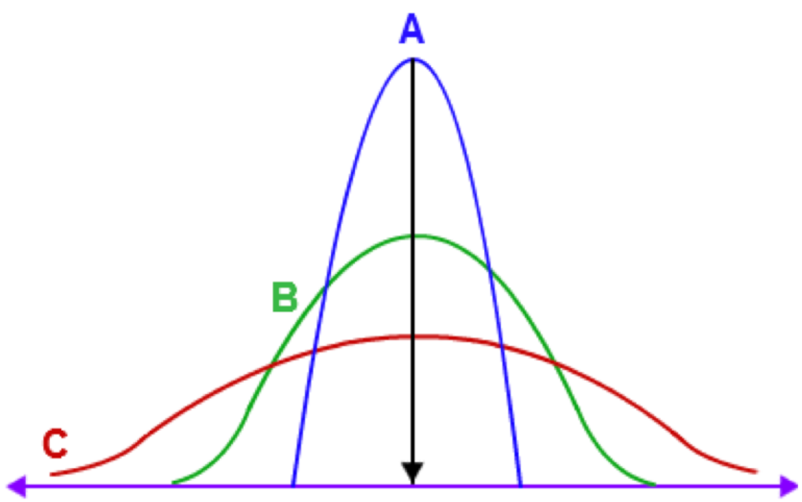
Dispersion relation: the concept

Simple linear case: uniform phase velocity

$$\omega(k) = c\ k$$

Most propagation speeds depend nonlinearly on the wavelength and/or frequency.

NB: for a **nonlinear** dispersion relation, the pulse will typically spread in either spatial frequency or temporal frequency as a function of time.



Example of pulse spreading spatially from time A to B to C.

http://www.mathcaptain.com/statistics/dispersion-statistics.html

Radar Physics - Part 1

What we covered

Basic properties of electromagnetic waves:

Phase and amplitude, angular frequency, wave number, constructive and destructive addition, polarization, phase velocity and group velocity, refraction and dispersion, concept of dispersion relation